

Water Flow Testing and Unsteady Pressure Analysis of a Two-Bladed Liquid Oxidizer Pump Inducer

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Abstract

The unsteady fluid dynamic performance of a cavitating two-bladed oxidizer turbopump inducer was characterized through sub-scale water flow testing. While testing a novel inlet duct design that included a cavitation suppression groove, unusual high-frequency pressure oscillations were observed. With potential implications for inducer blade loads, these high-frequency components were analyzed extensively in order to understand their origins and impacts to blade loading.

Water flow testing provides a technique to determine pump performance without the costs and hazards associated with handling cryogenic propellants. Water has a similar density and Reynolds number to liquid oxygen. In a 70%-scale water flow test, the inducer-only pump performance was evaluated. Over a range of flow rates, the pump inlet pressure was gradually reduced, causing the flow to cavitate near the pump inducer. A nominal, smooth inducer inlet was tested, followed by an inlet duct with a circumferential groove designed to suppress cavitation. A subsequent 52%-scale water flow test in another facility evaluated the combined inducer-impeller pump performance.

With the nominal inlet design, the inducer showed traditional cavitation and surge characteristics. Significant bearing loads were created by large side loads on the inducer during synchronous cavitation. The grooved inlet successfully mitigated these loads by greatly reducing synchronous cavitation, however high-frequency pressure oscillations were observed over a range of frequencies. Analytical signal processing techniques showed these oscillations to be created by a rotating, multi-celled train of pressure pulses, and subsequent CFD analysis suggested that such pulses could be created by the interaction of rotating inducer blades with fluid trapped in a cavitation suppression groove.

Despite their relatively low amplitude, these high-frequency pressure oscillations posed a design concern due to their sensitivity to flow conditions and test scale. The amplitude and frequency of oscillations varied considerably over the pump's operating space, making it difficult to predict blade loads.